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USE OF COMPUTERIZED COST MODELS IN COST ANALYSIS

Walter G. Hartung

April 1969

COST ANALYSIS DIVISION
COMPTROLLER
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

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FOREWORD

Within the Electronic Systems Division (ESD) the Staff Office specifically charged with the responsibility for development of estimating techniques, methods and procedures is the Comptroller Office (ESC). The content of this technical report was prepared by the Cost Analysis Division (ESCC) as an aid to improve cost estimating.

This Technical Report has been reviewed and is approved.

S. J. MACPHERSON, Lt Col, USAF
Chief, Cost Analysis Division
Comptroller

ABSTRACT

Cost analysis is a major function within the Department of Defense. Its application in cost effectiveness studies of large and complex military systems frequently requires the use of computerized cost models. This paper defines a cost model and discusses several important considerations in the development and use of such models. Models most useful in cost studies have all of the required computational algorithms, possess definitions for each cost element covered, and have the capability to differentiate variations in cost among several systems by considering parameters peculiar to each system. A system operating cost model for military jet transport aircraft is presented both to illustrate the format and content of a cost model and to indicate the applications of such models to cost studies. The input parameters and cost estimating relationships of this model are presented in Appendicies I and II of this report.

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ILLUSTRATIONS

SECTION I

INTRODUCTION

Cost analysis is an analytical process used to estimate the cost of resource requirements for military systems and programs. It is employed to derive and apply, for estimating purposes, relationships between resources consumed by current and past programs and those required for future systems. In addition, cost analysis is particularly concerned with examining the sensitivity of cost to varying assumptions regarding future systems, total force structures, and operational concepts. It employs the techniques of operations research, applied mathematics, economics, and engineering. Although dollars are used as a unit of measure for the diverse categories being examined, cost means the use of economic resources such as manpower, equipment, real facilities, and all other resources necessary for weapon and support systems and programs.

Cost is conceived as total life-cycle cost covering each phase of a program (i.e., conceptual, definition, acquisition, and operational). One of the most significant components of the total cost is that of system operation. It has been estimated that at least 20% - 30% of the total defense dollar goes directly into the operation of existing systems. Furthermore, life-time support costs often dominate system life-cycle costs by an order of at least ten times the original procurement cost.* It is not surprising, therefore, to realize that in order to properly compute and evaluate these resource ramifications, especially with respect to operating costs, a computerized cost model is required.

A cost model, as used in this paper, is a deterministic type model combining the techniques and elements of cost analysis into a unified and consistent structure. It is neither stochastic nor a simulation of a process. It evaluates resource requirements expressed in manpower and dollars, but it does not determine military effectiveness. Such a model consists of explicit definitions for each element of cost pertinent to the system. These definitions are made in terms of a cost estimating relationship (CER) which is any combination of the following: parametric equation, judgment factor, or a cost factor.

A parametric equation relates one or more system or subsystem parameters to cost. These equations are derived from pertinent historical data, primarily by regression analysis using one or more system parameters as explaining variables, or from engineering relationships. In the System Operating Cost Model to be presented, the fuel consumption per flying hour is expressed

*Goldman, Alan, "Life Cycle Support Cost Estimation," Reference 1 in terms of the aircraft's maximum speed, empty weight, specific fuel consumption (an engine variable) and maximum thrust. This expression was obtained from a regression analysis on historical data. Appendix II presents these and other estimating relationships of the System Operating Cost Model in detail.

Experience in the form of judgment factors is used to compute one cost in terms of another, more fundamental cost or resource. As an illustration, in the System Operating Cost Model, the cost to replenish the initial spare parts inventory for an aircraft is computed as a percent of the initial cost of that inventory.

Cost factors are generally accepted values derived from past experience. In the System Operating Cost Model, the cost of petroleum, oil, and lubricants (POL) is determined by multiplying the gallons of fuel consumed by a cost factor representing not only fuel cost but also oil and lubricants. Thus, the cost of oil and lubricants is given in terms of a composite cost and is expressed in a single cost factor.

SECTION II

ADVANTAGE OF COST MODELS

The advantages of using models in studies of large, complex multi-million dollar systems are derived primarily from the inherent requirements in model development and computer programming. Since the computer must have a precise description of the cost estimating methodology and the system being studied, the formulation of the system in terms of both cost and design evolves from nebulous descriptions to explicit specifications and definitions The decision maker is therefore provided with costs for explicit system configurations, and areas of sensitivity in terms of cost or effectiveness can be related to specific parameters in the design of the system. While a cost model will not make a decision, it will permit the decision maker to base his conclusions upon logically sound cost information derived from an explicit definition of the system and the cost methodology employed.

Documenting cost estimates has often proved to be a time-consuming task. Through the use of cost models, this problem can be substantially reduced. The computer program provides a written description not only of the system but also of the estimating methodology employed, and the printout of the results records the cost evolution of the system being studied.

Another advantage of computer models is the obvious one: It relieves the cost analysis staff of the burden of repetitive, time-consuming calculations. Not only can "I-needed-it-yesterday" requireme ts for cost data be met, but also, the analyst can present costs for many reasonable alternatives, include areas of sensitivity, and perhaps point out potential problems not readily apparent to the decision maker.

While these advantages would in themselves be sufficient to warrant the use of computer models in cost analysis, they are overshadowed by the depth of analysis which such models permit. Cost models enable the analyst to study the sensitivity of various parameters to the resources required by the system. Design cost trade-off studies providing significant cost information on the various feasible system configurations are possible, and costs for varying degrees of effectiveness can be easily determined for application in cost effectiveness studies. In addition, studies can be conducted to ascertain the cost sensitivity of various system parameters or specifications, thereby focusing the attention of the decision maker directly to specific areas where potential problems may develop.

SECTION III

LEVELS OF COST MODELS

There are many types of cost models in existence today. Such models can be divided into three general levels as shown in Figure 1. A level one model considers the cost effectiveness of the total force structure and as such would be used for planning the overall composition of the systems within the nation's inventory. Level one consists of those models which prepare cost projections for many systems. These models are primarily concerned with the economic interaction of all significant military systems. They accept as part of their cost input the results obtained from cost models developed for individual weapon systems.

The individual system models, known as life-cycle models, are level two models which compute cost estimates for a particular system in the three cost categories: Development, Investment, and Operating. Operating cost is usually computed on an annual basis for a given period of time, generally, five or ten years. Level two models utilize the results of the models for each of the three cost categories to determine the complete life-cycle cost for an individual weapon system. This life-cycle cost considers system production rate and phase-in, weapon system effectiveness, and the force structure within the system.

Level three models are used to derive specific costs and to accomplish detail system cost trade-off studies in the three major categories: Development, Investment, and Operating. These models may operate either independently or as subroutines within a level two model.

Use of level three models as subroutines is illustrated in Figure 2. Here, the system specifications and requirements are presented as inputs to a level two model. This model will then generate specific system input values for each of the level three models in order to obtain costs for a specific set of requirements and specifications. These specific values are obtained by considering the effects of varying certain system parameters. For example, costs may be desired for different quantities of aircraft within the system; however, varying this parameter may require that other system values, such as sortie length, be correspondingly changed. The costs from the level three subroutines are then used to determine the complete life-cycle cost for the given system inputs supplied by the level two model. The cycle from generating level three input to

HIERARCHY OF COST MODELS

Level One:	Cost model for high level planning considers all current or proposed systems Used for: Total force structure and planning Five Year Defense Plan
Level Two:	Cost model for individual weapon systems considers cost for a particular system Used for: Life-cycle cost Sensitivity studies Cost effectiveness studies Input to Level One programs
Level Three:	Cost model for one of the three following categories for a particular system: Development Investment Operating Used for: Detailed cost computations Sensitivity studies Design trade-off studies Input for Level Two models

Figure 1

INDIVIDUAL SYSTEM COST ANALYSIS

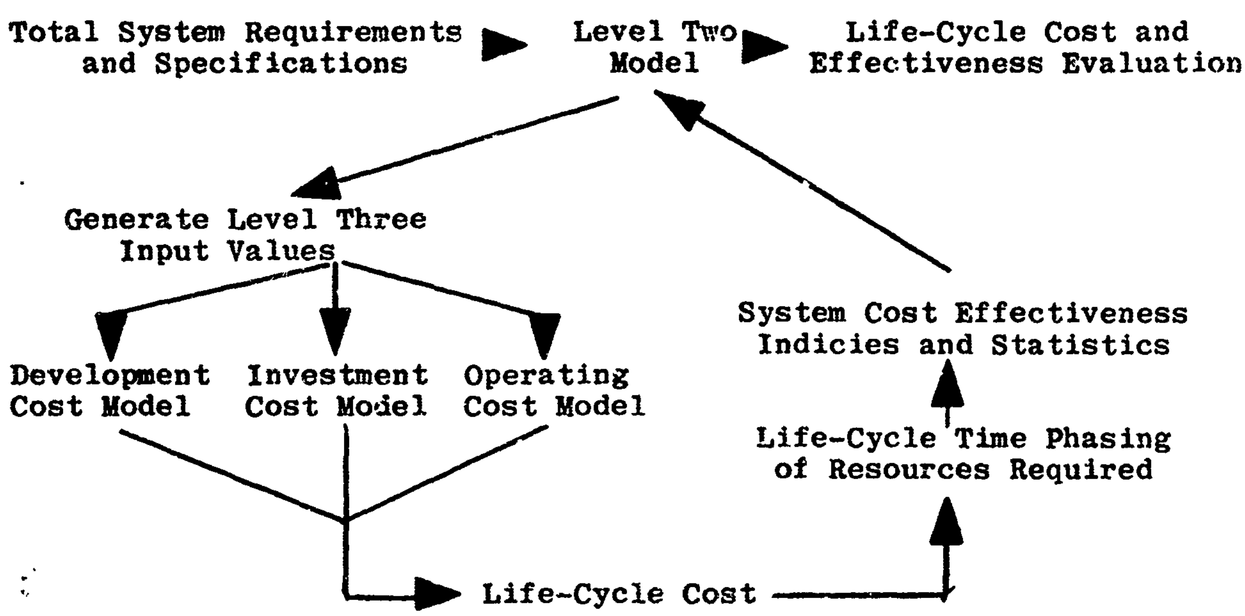

Figure 2

computing cost effectiveness statistics may be repeated either manually or by model design so that each variation in system requirements and specifications is evaluated.

An analysis on the life-cycle cost is performed to determine an efficient scheduling of funds. This involves the time phasing of resources which depends upon, among other things, force build-up, production rate, and level of effectiveness. Life-cycle costs also form a basis for system selection. The results from cost models form cost streams which cover a period of several years. These costs include both investment and operating dollars. By comparing the cost streams of competing systems, the system which is the most cost effective can be identified. This is accomplished by combining the dollar values of the stream using the approach of relating all future costs to an equivalent cost at the current time period. The author discusses this in detail in reference 8.

SECTION IV

COST MODEL CONSIDERATIONS

Since a cost model is an abstraction of the system to which it is applied, its structure is dependent upon the structure of the system. The elements of cost which are to be estimated are thus system dependent. This system dependence within the structure of a cost model is required if the model is to differentiate among the resources required by alternate or competing system configurations.

Attempts have been made to develop generalized cost models applicable to a variety of programs. Such models have presented a serious dilemma to the user; the input values of the model are more often than not a form of the output values required by the cost analyst. Models which require as input the number of maintenance personnel, the fuel cost per flying hour, depot maintenance cost per flying hour, or base materials cost per flying hour are of little use when these resources and costs are precisely what the analyst is attempting to determine. If the analyst must supply fuel cost per flight hour and the number of flying hours to arrive at the total fuel cost, he could just as well perform the trivial multiplication to obtain the cost. This, unfortunately, is the sad state of many existing computer models; their inputs are a form of the output values desired and normally require the use of outside estimating relationships, other models, or just plain guesswork.

In applying such models to evaluate several competing systems to determine which is most cost effective, the disadvantages are numerous. First of all, consider the fact that many estimating relationships use identical system parameters (e.g., weight, speed, and altitude). Hence, a parametric evaluation of several systems would require precomputation of each of the inputs affected by these parameters for each form of the systems being studied. This increases the probability of misapplication in that some of the input values affected by the changing system parameter may be neglected in the precomputation process.

A second disadvantage arises from the first in that the outside relationships, models, or guesses may not be consistent with the cost model. For example, one may apply a CER to compute maintenance costs per flight hour which includes manpower, material, and overhead, whereas the cost model may be structured such that it assumes the input to be solely a manpower cost and then computes material and overhead as a percentage of this input. Hence, material and overhead would be computed twice, and perhaps more. Because models and relationships are often poorly documented, terms imprecise, and pertinent estimating relationships hard to come by, thereby forcing one to make do with what is available, situations such as this are far too common.

In regard to the above remarks. the inefficiency in using the model presents a third disadvantage. When an analyst must deal with many variations of a system, and there are several systems to be evaluated, input preparation becomes prohibitive. As a result, cost studies tend to exclude many feasible alternates, thus diluting their efficacy.

Other disadvantages include nonavailability of pertinent estimating relationships to compute key input parameters, including guesses for inputs where small errors could produce sizeable errors in the cost estimate, and misapplication of the model by performing a cost effectiveness study on systems where the basis for computing the inputs has shifted from system to system.

Whether these disadvantages outweigh the advantage of generality is pure speculation. Certainly, if the analyst cannot apply the model because he cannot properly and efficiently determine the input values, the model is of no use to him. Where are the advantages to the user if he must utilize other models or estimating relationships just to compute input values? Results from misapplied models are perhaps even more serious. The consequences of misleading conclusions are erroneous decisions which place a wasteful drain on national resources.

There is no substitute for incorporating all the required estimating algorithms to construct a consistent, simple and easily applied cost model. For use in cost analysis, a model must be sensitive to and operate on the parameters of the system characteristics, requirements, and assumptions and then generate internally, intermediate values which will be used to arrive at a cost estimate. Rather than generating an ultimate general cost model, effort should be concentrated in developing and publicizing more specific models for more specific types of systems.

In addition to the above, cost analysis requires that the elements which comprise a model be well defined. Definitions of initial investment, recurring costs, overhead, facilities, etc., are not sufficiently explicit to insure that they mean the same things to all people. There have been as many as eleven difinitions given for the element depot maintenance.* Consider for

*Seidel, Irwin, "Maintenance Cost Estimating for Operational Systems," Reference 1 example the following definition of initial spares: "all costs required to maintain a stock of equipment, parts, and accessories necessary to maintain the production or investment program." It is not only impossible to calculate initial spares cost from this definition but also impossible to ascertain those items considered in this category. At what level are stocks to be maintained? Is an engine a replacement spare? How long is the stock level to be maintained? Thirty days? Have we considered items here which were also considered elsewhere? Have items been omitted? Clearly, estimates to this cost will vary significantly, depending on the person interpreting the requirement. It is thus mandatory that terms be defined from a computational aspect and be sufficiently explicit to identify all variables or items in the element.

SECTION V

SYSTEM OPERATING COST MODEL

A. Model Overview

The disadvantages of existing computer cost models prompted development of a model that would contain all pertinent estimating relationships and consist of a series of well defined cost elements. The model developed operates on input parameters which are descriptive of the type of system to be studied. The type of system under consideration consists of a military jet transport aircraft containing sophisticated electronic equipment. The model developed computes the annual operating cost of this system under peacetime conditions. Since differences exist between military and industrial accounting and maintenance procedures, this model is not directly applicable to a commercial operation.

The output of the model is shown in Figures 3 and 4. Essentially, this output represents the definition or composition of operating costs and reflects a structure peculiar to a specific set of military systems (i.e., it is not applicable to missile systems or fighter aircraft). It summarizes the various costs for aircraft, mission avionics (airborne electronic subsystem), and the total system. In addition, costs by major segment are depicted as percentages of total operating cost and are presented on a per flight hour and a per sortie basis. Personnel requirements are given by officer, airman, and civilian for the categories of operations, maintenance, administration, and support. Furthermore, personnel requirements for all maintenance are given in terms of manhours per flight hour.

The operating cost model consists of individual submodels or estimating relationships for each category shown in Figure 3. The estimating relationships were collected from many sources, tested for credibility, and represent what is believed to be the best available. In certain areas, such as mission avionics, historical data are insufficient and inconclusive to develop estimating relationships sensitive to equipment characteristics. As a result, judgment factors based upon either similar systems or engineering opinion are used which compute operating cost as a function of procurement cost. While such factors are consistent with the algorithms within the model, they represent areas where further study or information is required.

It is pointed out again that the estimating relationships in this cost model were chosen specifically to be representative

OPERATING COST OUTPUT FORMAT
ANNUAL PEACETIME OPERATING COSTS
(THOUSANDS OF DOLLARS)

	Aircraft	Mission Avionics	System	Percent	$/FH	$/Sortie
Maintenance	8744.	4533.	13277.	27.4	0.553	5.532
Depot	4476.					
Base	4268.					
POL	6450.		6450.	13.3	0.269	2.687
AGE	75.	320.	395.	0.8	0.016	0.164
Other	1520.	1865.	3385.	7.0	0.141	1.411
Spares Replenishment	6000.	2324.	8324.	17.1	0.347	3.468
Replacement Training	4643.	1481.	6124.	12.6	0.255	2.552
Pay and Allowances			9091.	18.7	0.379	3.788
Annual Travel			133.	0.3	0.006	0.056
Annual Transportation			125.	0.2	0.005	0.052
Annual Services			1249.	2.6	0.052	0.520
Total Annual Cost			48553.	100.0	2.023	20.230
Total Annual Flight Hours	24000.					
Total Annual Sorties	2400.					

Figure 3

OPERATING COST OUTPUT FORMAT

Total Personnel Requirements

Type	Officers	Airmen	Civilians	Total
Operations	206	260	0	466
Maintenance	114	2165	0	2279
Administration	82	279	11	372
Support	125	1121	311	1557
Total	527	3825	322	4674

Direct Maintenance Manhours/Flight Hour

Aircraft	
Depot	36.1
Base	34.4
Mission Avionics	50.0
Total	120.5

SAC System Tenant on SAC Base

Figure 4

of the class of military aircraft systems having the following characteristics: military jet transport, operating as a tenant at a military base. While relationships exist for other classes, they were not included in this model.

All computations are performed to reflect costs on an annual basis for one wing, since a wing operates as an independent entity. Personnel computations, especially administrative and support, are based upon this unit. As used in this model, a wing consists of one or more aircraft squadrons each having one or more unit equipment aircraft. Referring to Figure 3, we shall now present a brief description of the cost categories. In Appendix I, the input variables of this cost model are delineated. The mathematical details of the model are presented in Appendix II.

B. Aircraft Operating Cost Model

Maintenance costs for the aircraft are divided according to depot and base maintenance. The depot maintenance computation is based on the "Depot Maintenance Cost Summary" data and includes both in-house and contract maintenance cost not accomplished at the base level. The indirect maintenance and general and administrative cost generated at the depot organic maintenance facilities are also included. Material cost and government furnished equipment (GFE) cost to contractors are excluded. These costs are part of depot replenishment. The estimating relationship for this computation was obtained from reference 2 and relates cost to the weight of the airframe.

Base maintenance is determined from summarized manhour data collected by the AFM 66-1 maintenance system. This is a data management system which collects and summarizes maintenance information under various maintenance categories for aircraft within the Air Force inventory. The cost of base maintenance includes minor repairs and preventive maintenance such as flight line and periodic maintenance work performed in the fabrication, propulsion, and aerospace systems shop, and work performed in the communications, navigations, armament, electronics (excluding mission avionics), and photographic shops. Maintenance costs for survival equipment are also included. In addition, base maintenance also includes indirect costs such as absences, travel, overhead, quality control, material control and reports. The estimating relationship for this computation (reference 3) relates aircraft maximum altitude, maximum speed and sortie duration to the number of maintenance manhours per flying hour. The total manhour requirement is determined by multiplying the manhours per flying hour by the total number of hours. A cost factor is then employed to translate this manhour requirement to a dollar value. The number of maintenance personnel is derived from the total manhour value by dividing it by an annual work hour per man factor.

The next category consists of the petroleum, oil, and lubricants (POL) cost required for the flight program. The relationship for this computation was based on data which reflects world-wide Air Force POL consumption. The algorithm, discussed in reference 4, relates speed, weight, specific fuel consumption, and thrust to a figure reflecting POL consumption per flight hour. This gallon-per-flight-hour value is multiplied by an appropriate cost factor and by total flight hours to compute the POL cost estimate.

The cost of operating and maintaining base aerospace ground equipment includes repair, inspection, pickup and delivery of the peculiar ground equipment required to keep the mission aircraft operational. As discussed in reference 3, the estimating relationship computes maintenance manhours per flight hour as a function of maximum altitude, speed, and sortie length. This manhour value is then converted to a cost based upon the flight program and a cost factor representing an average hourly pay rate.

The miscellaneous category "other" includes such items as operating and maintaining program training devices, other base maintenance and support equipment and supplies. The computation is derived from reference 5 and is based upon a judgment factor representing expert consensus by taking a percentage of the initial cost for the procurement of the "other" items as the O&M cost.

The cost for replacing the initial stock for airframe, propulsion, AGE, and non-mission avionics is computed under the spares replenishment category. The algorithm for computing this cost, as discussed in reference 5, consists of taking as the cost a percentage of the initial procurement cost of spares. The value of this percent represents a judgment factor based upon experience.

Replacement training consists of the cost of training direct maintenance and operation military and civilian personnel due to turnover. For each category of officer, airman, and civilian personnel, the model is a summation of the training cost per man times the number of men times the turnover rate.

C. Mission Avionics Operating Cost Model

The above represents the cost elements for the aircraft portion of the cost model. Now, let us consider the mission avionics section of the model. Here, we consider electronic equipment on-board the aircraft whose mission is not related to the operation of aircraft itself. Such equipment may perform reconnaissance, command and control, countermeasure or other such functions.

Due to the absence of adequate historical data, maintenance cost for mission avionics is computed on the basis of two input factors. The factors are: (1) A judgment value for the number of manhours required; and (2) The material cost per flight hour required to operate and maintain the mission avionic equipment. These factors do not directly reflect equipment characteristics. Their values could be the result of engineering estimates, system specifications, or parameters to be varied in a cost sensitivity study. The computed cost represents the manpower and material cost to maintain the avionic subsystem.

The next cost category pertains to the avionic ground support equipment. Its operation and maintenance cost is computed on the basis of a judgment factor which expresses this cost as a percent of the initial (procurement) cost.

The computation for the "other" category is identical with that for the aircraft, with the exception that mission avionic factors are used. As with aircraft, this is a miscellaneous type category.

The algorithm for the computation of spares replenishment is an average of two methods, one developed at ESD and the other by RAND in reference 6. This relationship evaluates the cost as a function of initial mission avionic cost, the total annual flight hours, and the total annual number of sorties.

Replacement training costs are computed on an identical basis with that for aircraft. In this case, the pertinent factors are those for mission avionics; thus this cost represents the cost for replacement training of mission avionic operation and maintenance personnel. The cost for replacement training of administrative and support personnel is not considered since such costs are not properly identifiable with the [redacted] cost of operating a system.

D. Common System Operating Costs

Consideration is now given to those costs which are aggregated for the total system. These are pay and allowances, and annual travel, transportation, and services.

The model considers the annual pay and allowances for both military and civilian personnel. Since maintenance personnel were considered previously under the maintenance category, their pay and allowances are not computed here. Rather, this category considers only the cost of operating personnel (aircrew for both operating the aircraft and the mission avionics) and administrative and support personnel.

The cost of annual travel for military replacement personnel is computed based upon a turnover rate and a cost per man factor for all officers and airmen in the system. This cost also includes transportation of household goods and travel of dependents.

Reflected in annual transportation is the first and second destination cost for the transportation of replenishment spares for both aircraft and mission avionics. This cost is computed as a fraction of the replenishment spares cost for both the aircraft and mission avionics systems.

Annual services considers the cost of materials, supplies, contractual services, supply operations, food and medical services, and operation and maintenance of organizational equipment. The cost is computed by multiplying a cost per man factor by the number of military personnel within the system.

E. Model Output

All the computed costs are printed in the format shown in Figure 3. These costs are also presented as a percentage of the total operating cost, and in terms of a cost per flight hour and a cost per sortie. The printout also includes the total annual flight hours and the total annual sorties.

A second printout, Figure 4, shows the annual base personnel requirement to operate and maintain the system. The operations personnel consist of the aircrew required for both the operation of the aircraft and the mission avionics. The people under the maintenance category include base aircraft maintenance personnel, AGE base maintenance personnel, and mission avionics maintenance personnel. The personnel required to administer and support the base operations and maintenance people are also presented. The administrative personnel include those personnel assigned to Wing Headquarters, whereas support personnel are those assigned to the following base functions: Combat support, civil engineering, food services, security, supply, transportation, and medical services (reference 7).

Finally, the maintenance manhours per flight hour are given for both aircraft and mission avionics. Note that the value for mission avionics is an input value. The total maintenance manhours per flight hour and the maintenance dollars per flight hour are particularly useful items. This information is used in military planning and is vital to the costing of airborne systems. For new systems, a particularly useful check on the accuracy of per flight hour data is accomplished by referring to standard planning factors found in both military and commercial literature for similar aircraft and cost elements.

SECTION VI

APPLICATION

Using a computer model to evaluate costs for several system alternates permits comparison on an equivalent basis. Frequently, in studying such alternates, simple relationships may be derived to express incremental costs within a system, even though such costs themselves are complicated functions of many heterogeneous system parameters. For a given level of combat effectiveness, comparisons among alternate possibilities can be realized in terms of one or two key system parameters. Also, cost sensitivity analyses which measure the effect of variations in system parameters and requirements on total cost, or a portion thereof, may be performed. Such analyses provide an indication of areas of exceptional sensitivity which may require further consideration.

To illustrate, let us consider a system consisting of a jet transport carrying sophisticated electronic surveillance equipment. Each aircraft is to have a sortie length of twenty hours, which includes both time on station and flight time to and from station. The annual flying time for each aircraft in the system is 850 hours. Assuming that the mission avionics will require ten manhours per flight hour for maintenance and twelve dollars per flight hour for maintenance materials, we should like to know the incremental annual operation and maintenance cost with respect to additional aircraft.

The cost model was presented with this information and costs were computed for systems having from two to twenty aircraft. The results are plotted in Figure 5. From this figure we can observe that the incremental operating cost (i.e., the cost for an additional unit) is 2.6 million dollars. Hence, ten aircraft would cost $40.5 million, whereas two additional aircraft would cost $5.2 million extra, or $45.7 million in total. The equation shown in Figure 5 illustrates how complex interactions of many heterogeneous variables can be brought together into a single, simple algabraic relationship between a key system parameter, such as the number of aircraft, and the system operating cost. Such results are invaluable in evaluating many system alternatives.

Still using the same type of system, let us consider operating costs for a given level of effectiveness. In this case, we require a constant 24,000 flying hours per year and would like to investigate the effects on operating cost as the number of aircraft and sortie length are varied while the

OPERATING COST AS A FUNCTION OF
THE NUMBER OF AIRCRAFT

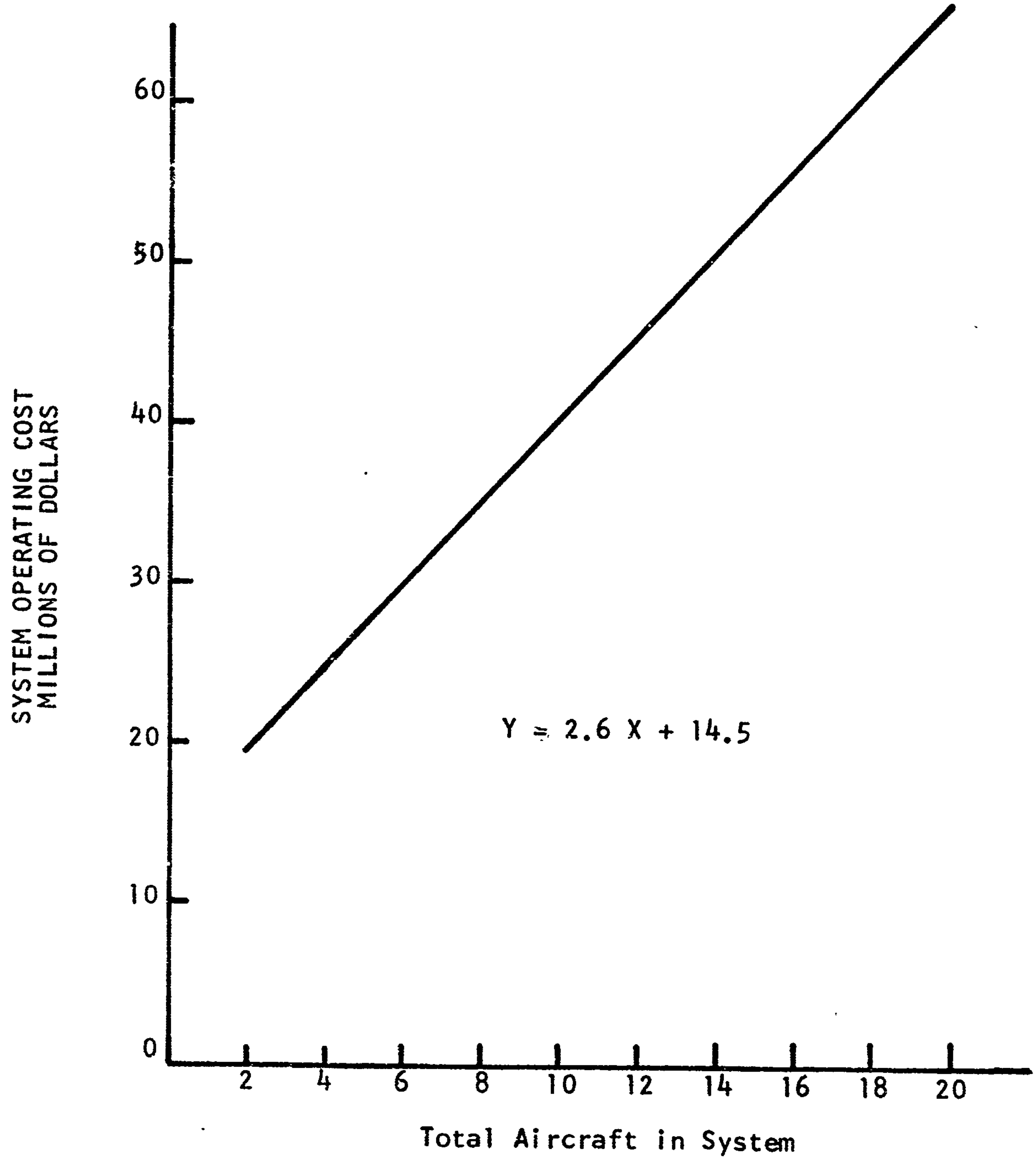

Figure 5

total annual flying hours and sortie rate are held constant. The relationship between sortie length and number of aircraft is shown in Figure 6. The associated operating cost is obtained from the model and is shown in Figure 7. We observe that for sortie lengths greater than fifteen hours, the rate of operating cost savings as the number of aircraft are reduced, is itself reduced. Thus, for systems containing less than thirteen aircraft, the potential operating cost savings gained by increasing sortie length vanishes. In Figures 6 and 7, the sortie rate was fixed at 10 per month. Similar plots could be made for other sortie rates, thereby forming a basis for selecting a least cost system on both sortie length and sortie rate. Furthermore, realizing that increasing the sortie length capability increases the investment cost per aircraft, we have an additional cost trade off between investment cost and sortie length which would be considered in a complete analysis.

In the example considered, on the basis of least system operating cost, the optimum system would have a sortie length of fifteen hours, since greater lengths do not produce significant operating cost reductions and increase investment cost. Thus, the optimum system would contain fourteen aircraft, each flying 120 sorties per year (10/month). Had other sortie rates and investment cost been considered, the operating cost model could have been used to select the optimum system by considering investment as an additive cost to operating cost, together with sortie length and sortie rate.

Finally, let us consider the sensitivity of mission avionic maintenance manhours per flying hour both to total system operating cost and to system maintenance cost. The cost model yielded the results shown in Figures 8 and 9. Here, a linear relationship exists between cost and mission avionic maintenance manhours per flying hour. This was to be expected since the only parameter, manhours per flying hour, was varied freely, and the system was not forced to meet prescribed levels of effectiveness. The incremental costs are easily obtained for the total operating category and for total maintenance. As would be expected, the incremental cost is most pronounced for maintenance since this represents a subcost of the total operating cost. Such costs would then be used in conjunction with an effectiveness study to determine cost as a function of effectiveness.

From Figure 8 we can see that doubling the mission avionics maintenance manhours from twenty to forty increases the total annual operating cost from $45.2 to $47.5 million. That is, a 100% increase in the maintenance resource for mission avionics produces a 5% increase in the total system operating cost. With regard to system maintenance cost, an identical

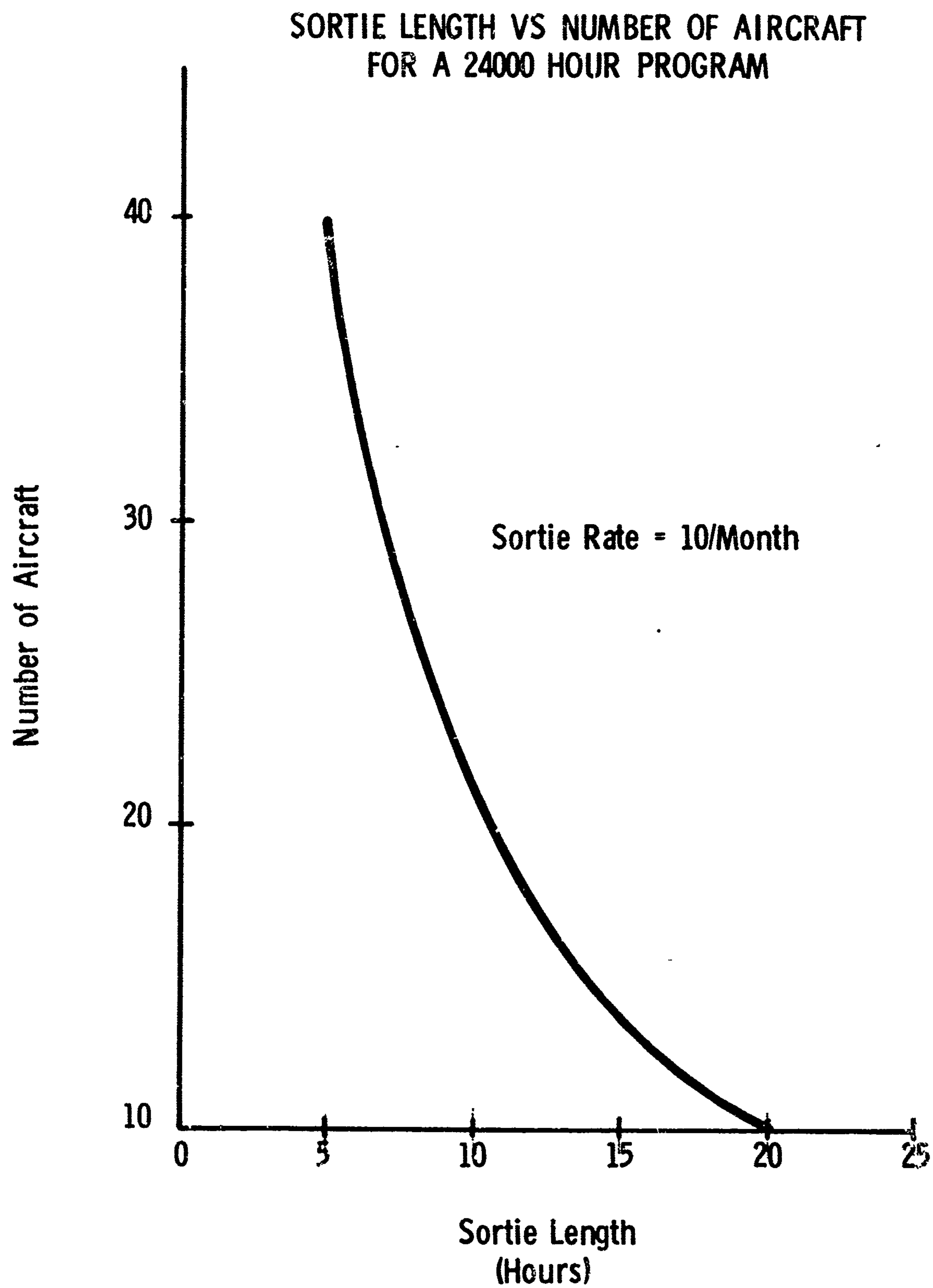
SORTIE LENGTH VS NUMBER OF AIRCRAFT
FOR A 24000 HOUR PROGRAM
Number of Aircraft
40
30
20
10
Sortie Rate = 10/Month
0
5
10
15
20
25
Sortie Length
(Hours)

Figure 6

SYSTEM OPERATING COST VS SORTIE LENGTH
FOR A 24000 HOUR PROGRAM

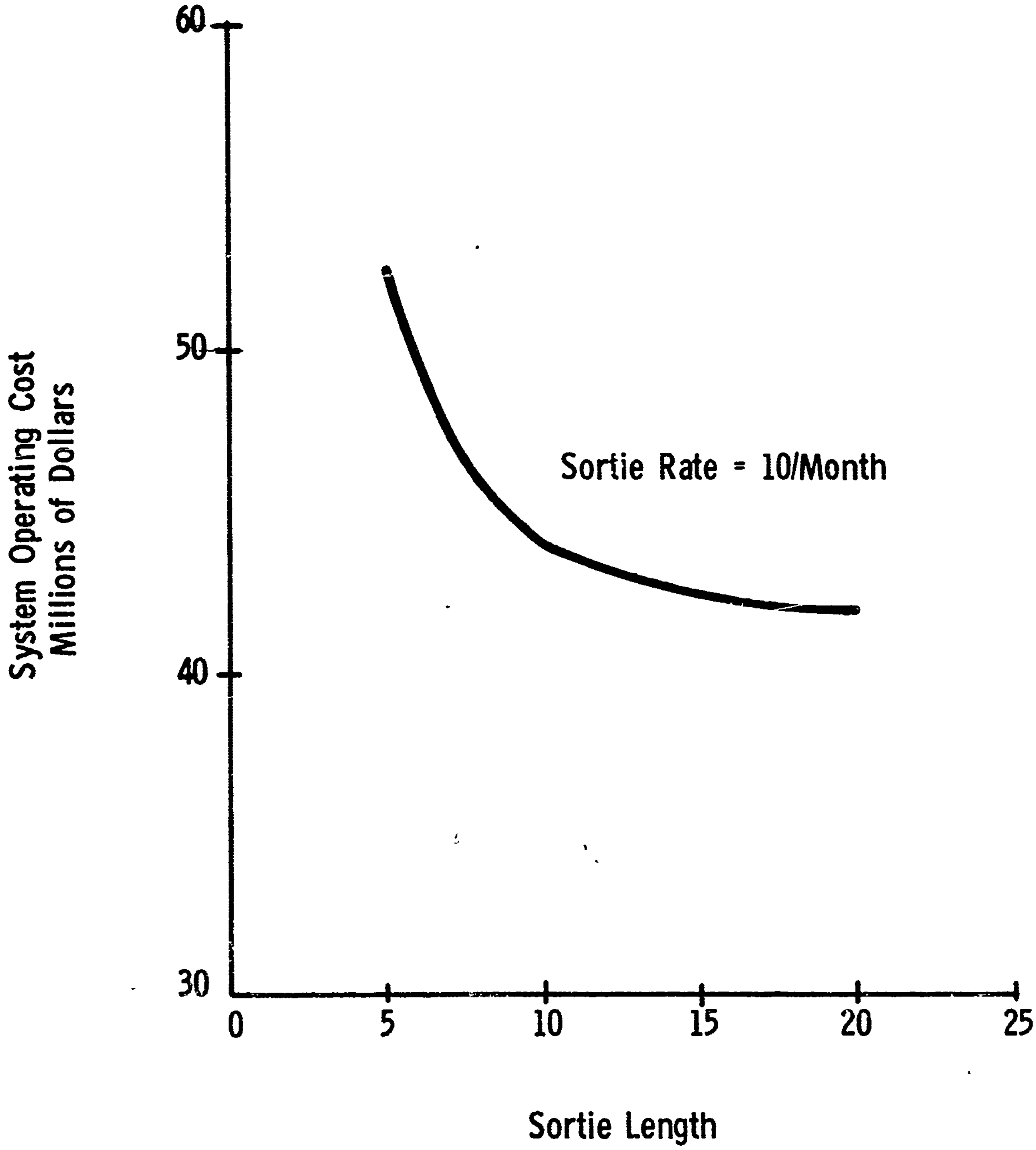

Figure 7

SYSTEM OPERATING COST VS MISSION AVIONICS
MAINTENANCE MANHOURS PER FLYING HOUR

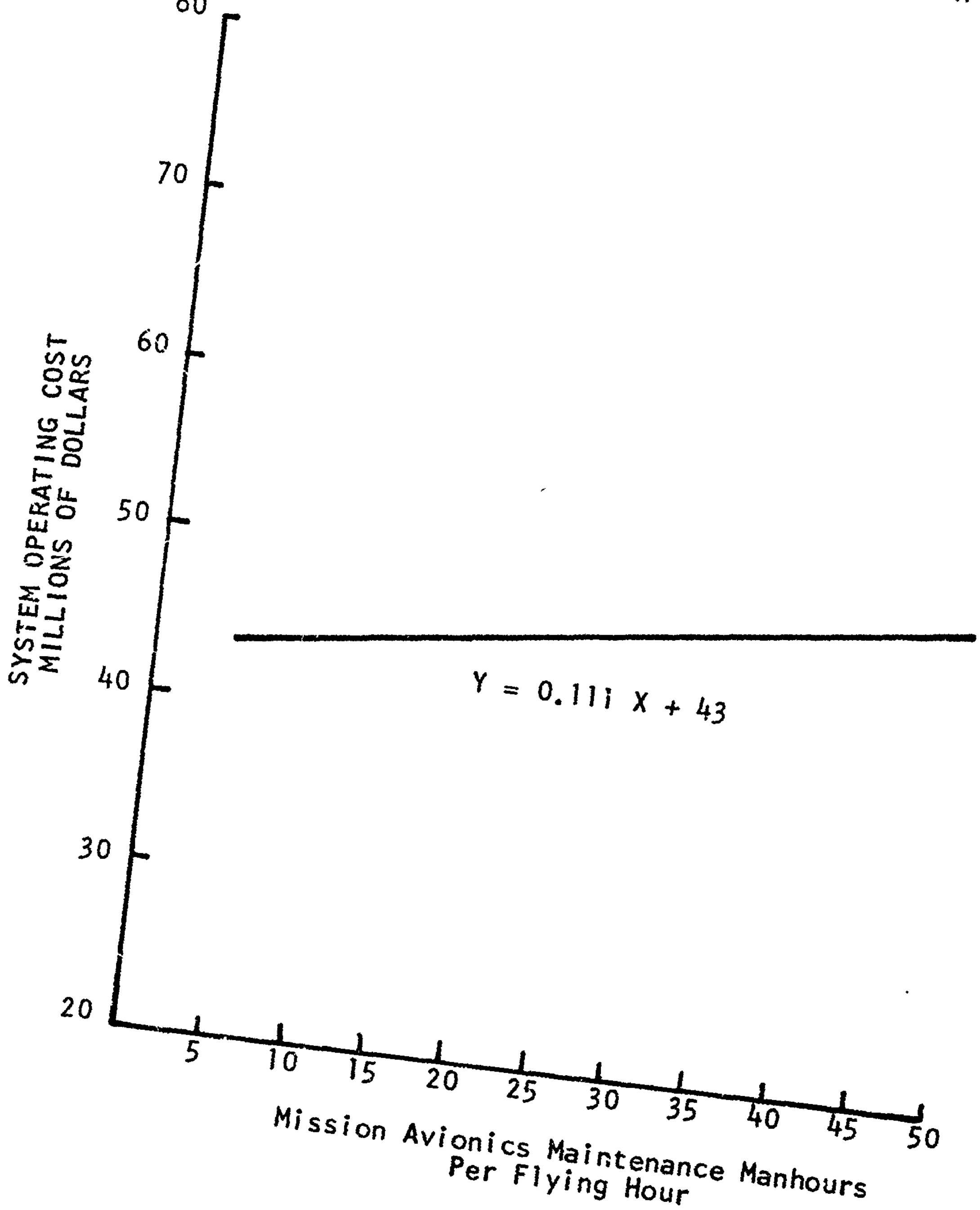

Figure 8

SYSTEM MAINTENANCE COST VS MISSION AVIONICS MAINTENANCE MANHOURS PER FLYING HOUR

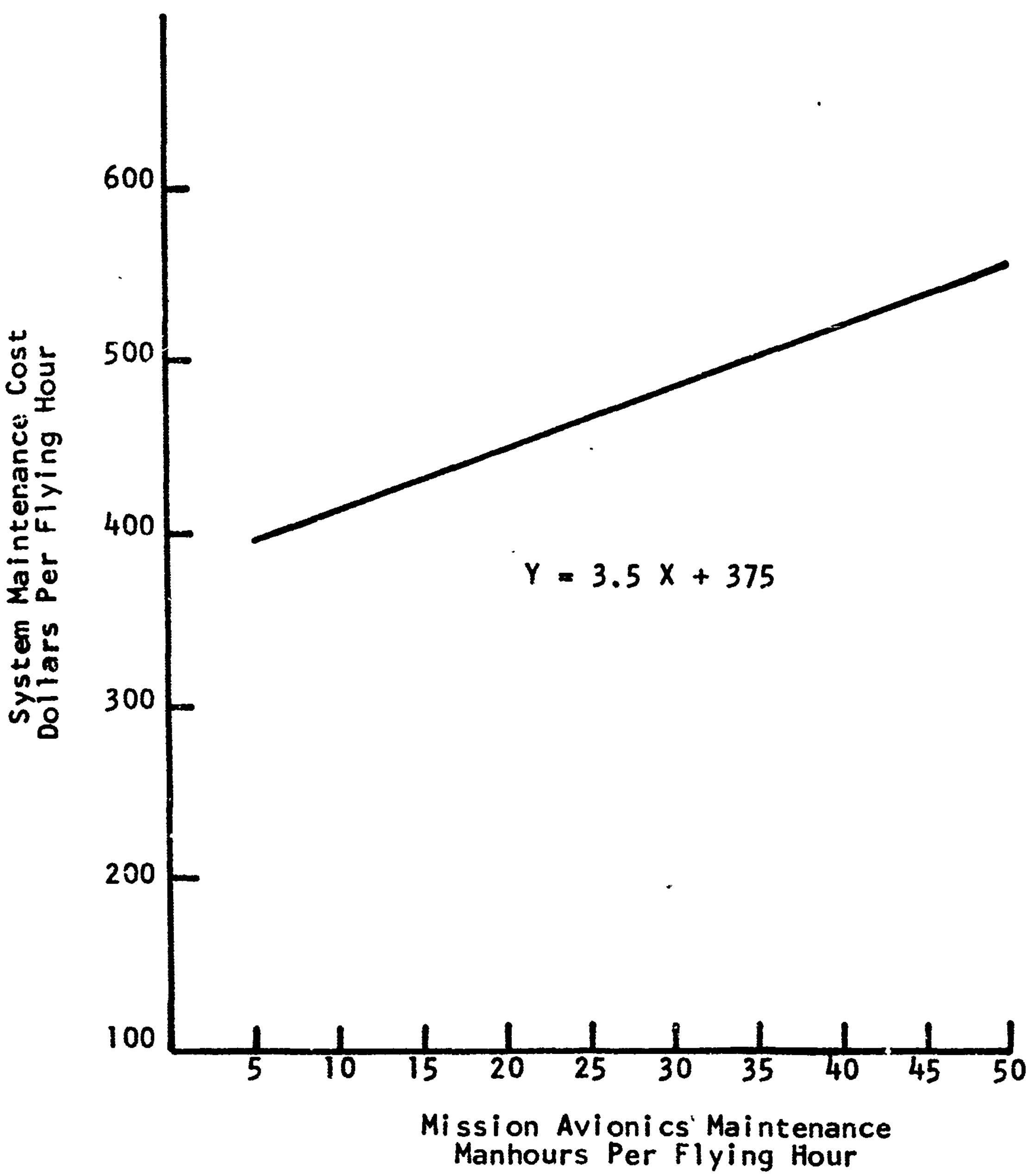

Figure 9

doubling of manhours increased the total maintenance cost per flying hour by 16%. Here, we were able to observe the effect of mission avionic maintenance manhour requirements not only on total system operating cost, but also on the single cost element of maintenance for both aircraft and mission electronics.

The above illustrates how the model is employed to measure the sensitivity of a parameter both to the cost of a total category and to the cost of a particular element of it. Such information is of particular importance in learning the effect of a system performance requirement on cost. In this particular case, its contribution to the total operating cost was small; that is, cost was not very sensitive to mission avionic maintenance requirements. Furthermore, because of the state-of-the-art in avionic cost methodology, the maintenance manhour parameter represents a judgment factor. As such, its effect upon cost required exploration. Had the sensitivity of this factor upon cost been greater, better knowledge of the relationship between avionic equipment characteristics and cost would have been required to obtain a more precise manhour factor for the particular equipment characteristics.

In contrast with the types of cost studies already outlined, the model may be used to examine the cost methodology itself. There are many instances in which the analyst may have more than one method for obtaining a given cost. Here, the model can be used to compare both the overall and individual results obtained by the use of different approaches, enabling one to derive the best explanation of cost and the sensitivity of cost to both the method and the parameters within the method. The relationship and variables which best explain cost is of value not only to the cost analyst but also to the engineer. In this regard, the model also presents an opportunity to ascertain the reasonableness of cost variations with system parameter variations and different estimating approaches. How much should a 10% increase in aircraft weight increase POL cost? If the increase seems too large, perhaps either the method or parameter does not properly explain cost. From an engineering viewpoint, should weight have the influence on cost as indicated by the model? Will a simple cost factor or a judgment factor give equally valid results as are obtained from complicated regression equations? Such inquiries are possible through use of cost models and serve to create a better understanding among methodology, system design, and cost.

SECTION VII

CONCLUSION

The increasing complexity of military systems has precipitated requirements for sophisticated cost methodology. The concept of cost has grown in scope from procurement dollars to total resource requirements consumed during the entire life of a system.

To meet the demands generated by complex systems and the broader concept of cost, cost analysis has placed greater emphasis on the application of computerized cost models. By using a model which accurately reflects the cost structure of a system, studies are possible which relate system specification, performance, and requirement parameters as well as methodology to the total resources required to bring a system into existence and maintain it during its operational life.

Through use of computer models, cost can be presented not only in terms of effectiveness, but also in units representing incremental system changes and realistic assumptions concerning the accuracy of values upon which individual estimates are based. With the speed of computation available, many system alternatives are able to be costed at a level of detail and thoroughness not previously attainable for a single case. Areas of uncertainty and variability can be investigated in terms of their sensitivity to cost. Finally, the model presents an opportunity to develop better and more meaningful cost methodology, enabling the cost analyst to explore the many approaches to cost estimation and resource allocation.

SECTION VIII

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APPENDIX I

SYSTEM OPERATING COST MODEL INPUT VALUES

A. System Inputs

S1 - Maximum altitude, K-ft
S2 - Maximum speed, knots
S3 - Sortie length, hours
S4 - Number of flight hours per year per aircraft
S5 - Number of unit equipment (U.E.) aircraft per squadron
S6 - Aircraft empty weight, pounds
S7 - Specific fuel consumption (lb/hr/lb)
S8 - Maximum thrust, pounds
S9 - Organizational Indicator

1 TAC Tenant on TAC Base
2 ADC Tenant on ADC Base
3 SAC Tenant on SAC Base
4 ADC or TAC Tenant on SAC Base

B. Personnel Inputs

P1 - Number of squadrons per wing, aircraft squadrons
P2 - Officers/aircraft, aircrew
P3 - Airmen/aircraft, aircrew
P4 - Percent officers, aircraft maintenance squadron
P5 - Percent airmen, aircraft maintenance squadron
P6 - Percent civilians, aircraft maintenance squadron
P7 - Officers/aircraft, aircrew, mission avionics
P8 - Airmen/aircraft, aircrew, mission avionics
P9 - Civilians/aircraft, aircrew, mission avionics
P10- Percent officers, mission avionics maintenance squadron
P11- Percent airmen, mission avionics maintenance squadron
P12- Percent civilians, mission avionics maintenance squadron
P13- Percent officers per wing, administration
P14- Percent airmen per wing, administration
P15- Percent civilians per wing, administration
P16- Percent officers per wing, support
P17- Percent airmen per wing, support
P18- Percent civilians per wing, support
P19- Percent officer turnover
P20- Percent airman turnover
P21- Percent civilian turnover

C. Initial Cost Inputs (Millions of Dollars)

I1 - Airframe spares
I2 - Propulsion spares
I3 - Avionic spares not related to mission avionics

I4 - AGE
I5 - Training investment, aircraft
I6 - Other initial investment in maintenance and support equipment, aircraft
I7 - Mission avionics, per aircraft
I8 - Training investment, mission avionics
I9 - Other initial investment in maintenance and support equipment, mission avionics
I10- Mission avionics ground support equipment

D. Judgment Factor Inputs

J1 - Spares replenishment cost as a fraction of initial investment
J2 - Operation and maintenance of other equipment as a fraction of training investment and other base maintenance and support equipment
J3 - Cost per man for other equipment and supplies replenishment
J4 - Fraction of organizational equipment replacement, AGE replacement, and base maintenance materials for transportation
J5 - Cost per man for annual services
J6 - Mission avionics spares as a fraction of initial cost
J7 - Mission avionics maintenance man hours per flight hour
J8 - Percent of 140 hours per month represented as actual direct working hours

In the cost model, a 10% allowance is made for Chief of Maintenance (quality control, materiel control, records and reports, etc.). Hence, maintenance overhead is computed by multiplying the direct maintenance cost by the factor 1.1 + .01 x J8. This new factor is redefined as J8 and is used as such in Appendix II.

J9 - Mission avionics AGE maintenance as a fraction of initial cost
J10- Material dollars per flight hour for mission avionics maintenance

E. Cost Factors

F1 - Cost per man for annual services, same as J5
F2 - Average annual pay, aircrew officers
F3 - Average annual pay, ground crew officers
F4 - Average annual pay, ground crew civilians
F5 - Average annual pay, aircrew airmen
F6 - Average annual pay, ground crew airmen
F7 - Average annual pay, mission avionics officers
F8 - Average annual pay, mission avionics airmen

F9 - Average annual pay, mission avionics civilians
F10- Average PCS travel cost per officer
F11- Average PCS travel cost per airman
F12- Aircrew officer replacement training cost
F13- Aircrew airman replacement training cost
F14- Ground crew officer replacement training cost
F15- Ground crew airman replacement training cost
F16- Ground crew civilian replacement training cost
F17- Mission avionics officer replacement training cost
F18- Mission avionics airman replacement training cost
F19- Mission avionics civilian replacement training cost
F20- Average annual salary, base maintenance personnel
F21- Cost per gallon of aircraft fuel

APPENDIX II

SYSTEM OPERATING COST MODEL ESTIMATING RELATIONSHIPS

A. Aircraft Submodel

1.0 Depot Maintenance Cost

$$C1 = (1.227 \times S6 \times 10^{-3} + 2.46) \times S4 \times S5 \times P1$$

2.0 Base Maintenance

2.1 Maintenance Manhours per monthly flying hour (TM)

$$TM = 14.7 + 8.92 \times S1^3 \times 10^{-5} + 1.05 \times S2^3 \times 10^{-9} + 1.32 \times S3$$

2.2 Maintenance Manhours per month (TP)

$$TP = TM \times S4 \times S5 \times P1/12$$

2.3 Maintenance Manhours per month for survival equipment (AF)

$$AF = 420, \ TP \leq 210 \text{ hours}$$
$$AF = 420 + (TP - 210)/98, \ TP > 210 \text{ hours}$$

2.4 Base Maintenance Cost

$$C2 = (TP + AF) \times J8/140 \times (P4 \times F3 + P5 \times F6 + P6 \times F4)$$

3.0 POL

3.1 Consumption in terms of gallons per flight hour (GP)

$$GP = 100 \times \text{ANTILOG}\,(-0.32528 + 0.37545 \times \text{LOG}\,(S2 \times S8 \times S7 \times S6 \times 10^{-8}))$$

3.2 Cost

$$C3 = GP \times S4 \times S5 \times P1 \times F21$$

4.0 AGE

4.1 Maintenance Manhours/month (BF)

$$BF = 560, \ TP \leq 388$$
$$BF = 560 + (TP - 388)/105, \ TP > 388$$

4.2 Cost

C4 = BF x J8/140 x (P4 x F3 + P5 x F6 + P6 x F4)

5.0 Personnel Computations

5.1 Personnel in an Aircraft Maintenance Squadron (ARK)

ARK = (TP + AF + BF) x J8/140/P1

5.2 Personnel in an Aircraft Maintenance Squadron by Category

P4 = P4 x ARK/100, officers
P5 = P5 x ARK/100, airmen
P6 = P6 x ARK/100, civilians

6.0 Other

C5 = J2 x (I5 + I6 + J3 x (P2 + P3 + P4 + P5) x P1)

7.0 Spares Replenishment

C6 = J1 x (I1 + I2 + I3 + I4)

8.0 Replacement Training

C7 = P1 x (P2 x F12 x P19 + P4 x F14 x P19 + P3 x F13 x P20 + P5 x F15 x P20 + P6 x F16 x P21)/100

B. Mission Avionics Submodel

1.0 Maintenance Personnel

1.1 Maintenance Personnel (FH)

FH = S4 x S5 x P1 x J7/1680

1.2 Maintenance Personnel by Category

P10 = FH x P10/100
P11 = FH x P11/100
P12 = FH x P12/100

1.3 Total Maintenance Cost

C8 = P10 x F7 + P11 x F8 + P12 x F9 + J10 x S4 x S5 x P1

2.0 AGE

C9 = J9 x I10

3.0 Other

$$C10 = J2 \times (I9 + I8 + J3 \times (P7 + P8 + P10 + P11) \times P1)$$

4.0 Spares Replenishment

$$C11 = 0.5 \times (I7 \times 4.2 \times S4 \times S5 \times P1 + I7 \times 1.3 \times S4 \times S5 \times P1/S3) \times 2.8 \times 10^{-6} + 0.5 \times J6 \times I7 \times S5$$

5.0 Replacement Training

$$C12 = P1 \times (P7 \times F17 \times P19 + P8 \times F18 \times P20 + P9 \times F19 \times P21 + P10 \times P19 \times F14 + P12 \times P21 \times F16 + P11 \times P20 \times F15)/100$$

C. Common System Operating Cost Submodel

1.0 Base Personnel

1.1 Total Base Operating and Maintenance Personnel (TOM)

$$TOM = (P2 + P4 + P7 + P10) \times P1 + (P3 + P5 + P8 + P11) \times P1 + (P6 + P9 + P12) \times P1$$

1.2 Total Administrative (AP) and Support (SP) Personnel

1.2.1 TAC System Tenant on TAC Base (S9 = 1)
AP = 0.0
SP = 0.427 x TOM

1.2.2 ADC System Tenant on ADC Wing Base (S9=2)
AP = 0.0
SP = 0.1668 x TOM

1.2.3 SAC System Tenant on SAC Base (S9=3)
AP = 0.1203 x TOM
SP = 0.3068 x (TOM + AP)

1.2.4 ADC or TAC Tenant on SAC Base (S9 = 4)
AP = 0.0
SP = 0.3068 x TOM

1.3 Total Administration and Support Base Personnel by Category
P13 = AP x P13/P1/100, officers in administration
P14 = AP x P14/P1/100, airmen in administration
P15 = AP x P15/P1/100, civilians in administration
P16 = SP x P16/P1/100, officers in support
P17 = SP x P17/P1/100, airmen in support
P18 = SP x P18/P1/100, civilians in support

2.0 **Pay and Allowances**

C13 = P1 x (P7 x F7 + P8 x F8 + P9 x F9 + P2 x F2
+ P3 x F5 + (P13 + P16) x F3 + (P14 + P17) x
F6 + (P15 + P18) x F4)

3.0 **Annual Travel**

C14 = F10 x P19 x (total number of officers)/100
+ F11 x P20 x (total number of airmen)/100

4.0 **Annual Transportation**

C15 = J4 x (C6 + C12)

5.0 **Annual Services**

C16 = J5 x (total number of officers and airmen)

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13. ABSTRACT

Cost analysis is a major function within the Department of Defense. Its application in cost effectiveness studies of large and complex military systems frequently requires the use of computerized cost models. This paper defines a cost model and discusses several important considerations in the development and use of such models. Models most useful in cost studies have all of the required computational algorithms, possess definitions for each cost element covered, and have the capability to differentiate variations in cost among several systems by considering parameters peculiar to each system. A system operating cost model for military jet transport aircraft is presented both to illustrate the format and content of a cost model and to indicate the applications of such models to cost studies. The input parameters and cost estimating relationships of this model are presented in Appendicies I and II of this report.

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